U.S. MARKET CONSEQUENCES OF GLOBAL CLIMATE CHANGE

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This paper summarizes two economic modeling efforts commissioned by the Pew Center on Global Climate Change. The first[1] develops an integrated assessment of the potential consequences of climate change on the U.S. economy. The second[2] analyzes the important role of multiple gases for cost-effective mitigation of global climate change impacts.

The first study aims to advance understanding of the potential consequences of global climate change. The Intergovernmental Panel on Climate Change (IPCC) predicted that average global temperatures could rise anywhere from 1.4^{o}C to 5.8^{o}C (2.5-10.4^{o}F) over the 21st century, with warming for the United States as much as 30 percent higher. This study examines the overall effect on the U.S. economy of predicted impacts in key market activities that are likely to be particularly sensitive to future climate trends. These activities include crop agriculture and forestry, energy services related to heating and cooling, commercial water supply, and the protection of property and assets in coastal regions. Also considered are the effects on livestock and commercial fisheries and the costs related to increased storm, flood and hurricane activity. Finally, the analysis accounts for population-based changes in labor supply and consumer demand due to climate-induced mortality and morbidity. Impacts in each of these areas were modeled to estimate their aggregate effect on national measures of economic performance and welfare, including gross domestic product (GDP), consumption, investment, labor supply, capital stock and leisure.

Importantly, this analysis does not consider the non-market impacts of climate change such as changes in species distributions, reductions in biodiversity, or losses of ecosystem goods and services. These considerations are essential to a complete valuation of the consequences of climate change but are very difficult to value in economic terms. A companion Pew Center report[3], provides more detail on the relative vulnerability of different U.S. regions to both the market and non-market impacts of climate change.

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[1] Jorgenson D., R. Goettle, B. Hurd, and J. Smith (2004), *U.S. Market Consequences of Global Climate Change*, Pew Center on Global Climate Change, Arlington, VA.
[2] Reilly J., H. Jacoby and R. Prinn (2003), *Climate Impacts and Mitigation Costs of Non-CO_2 Gases: Multi-gas Contributors to Global Climate Change*, Pew Center on Global Climate Change, Arlington, VA.
[3] Smith J. (2004) *A Synthesis of Potential Impacts of Climate Change on the United States*, Pew Center on Global Climate Change, Arlington, VA.

To capture the range of market consequences potentially associated with climate change in the United States and to address the considerable uncertainties that exist, several distinct scenarios were developed for this analysis. Each incorporates different assumptions about the magnitude of climate change over the next century and about the direction and extent of likely impacts in the market sectors analyzed. Specifically, three different levels of climate change (low, central and high) were considered in combination with two sets of market outcomes (optimistic and pessimistic) for a total of six primary scenarios. In terms of climate, the low, central and high scenarios encompass projected increases in average temperature ranging from 1.7^{o}C to 5.3^{o}C (3.1-9.5^{o}F) by 2100, together with precipitation increases ranging from 2.1 to 6.6 percent and sea-level rise ranging from 17.2 to 98.9 cm (7-40 inches) over the same period. In terms of impacts, the optimistic and pessimistic scenarios reflect a spectrum of outcomes from the available literature concerning the sensitivity of each sector to climatic shifts and its ability to adapt. As one would expect, the optimistic scenarios generally project either smaller damages or greater benefits for a given amount of climate change compared to the pessimistic scenarios. Because several of the market sectors included here are especially sensitive to changes in precipitation, two additional scenarios were analyzed. The first assumes the high degree of temperature change combined with lower precipitation ("high and drier") while the second assumes the low level of temperature change combined with higher precipitation ("low and wetter").

By introducing the sector-specific damages (or benefits) associated with each of these scenarios into a computable general equilibrium model that simulates the complex interactions of the U.S. economy as a whole, the combined effect of climate impacts across multiple sectors could be assessed in an integrated fashion. Detailed results are described in the body of this report, but five principal conclusions emerge:

1) Based on the market sectors and range of impacts considered for this analysis, projected climate change has the potential to impose considerable costs or produce temporary benefits for the U.S. economy over the 21st century, depending on the extent to which pessimistic or optimistic outcomes prevail. Under pessimistic assumptions, real U.S. GDP in the low climate change scenario is 0.6 percent lower in 2100 relative to a baseline that assumes no change in climate; in the high climate change scenario, the predicted reduction in real GDP is 1.9 percent. Under the additional "high and drier" climate scenario, however, real GDP is reduced more dramatically—by as much as 3.0 percent by 2100 relative to baseline conditions. Furthermore, under pessimistic assumptions negative impacts on GDP grow progressively larger over time, regardless of the climate scenario. In contrast, under optimistic assumptions real U.S. GDP by 2100 is 0.7 to 1.0 percent higher than baseline conditions across the low, central and high climate scenarios, but these benefits eventually diminish over time. Nevertheless, to the extent that responses in certain key sectors conform to the optimistic scenarios, there is a distinct possibility that some degree of climate change can provide modest overall benefits to the U.S. economy during the 21st century.

2) Due to threshold effects in certain key sectors, the economic benefits simulated for the 21st century under optimistic assumptions are not sustainable and economic

damages are inevitable. In contrast to the pessimistic scenarios which show increasingly negative impacts on the economy as temperatures rise, the economic benefits associated with optimistic scenarios ultimately peak or reach a maximum. Specifically, the agriculture and energy sectors initially experience significant cost reductions, but only so long as climate change remains below critical levels. Once temperature and other key climate parameters reach certain thresholds, however, benefits peak and begin to decline—eventually becoming damages. Different thresholds apply in different sectors and the time required to reach them depends on the rate at which warming occurs. In the high climate change scenario, the trend toward economic benefits under optimistic assumptions slows and peaks around mid-century, whereas, in the central climate case, this transition appears toward century's end. In the optimistic, low climate change scenario, benefits continue to accrue throughout the 21st century. Nevertheless, the existence of these thresholds means that continued climate change—even if it proceeds slowly—eventually reverses market outcomes so that predicted economic benefits are only transient and temporary.

3) The effects of climate change on U.S. agriculture dominate the other market impacts considered in this analysis. Currently, the agriculture, forestry and fisheries industries represent about 2.0 percent of total U.S. industrial output and about 3.5 percent of real GDP. However, agriculture accounts for a much larger share of the overall climate-related economic impact estimated in this analysis. For example, across the low, central and high climate change scenarios, field crop and forestry impacts account for over 70 percent of the total predicted effect of climate change on real GDP under optimistic assumptions and almost 80 percent of the total GDP effect under pessimistic assumptions. These figures rise to 75 and 85 percent, respectively, if one includes climate effects on livestock and commercial fisheries. Clearly, significant impacts in relatively small sectors can exert a disproportionate influence on the overall economic consequences of a given climate change.

4) For the economy, wetter is better. All else being equal, more precipitation is better for agriculture—and hence better for the economy—than less precipitation. Not surprisingly, reductions in precipitation are costlier at higher temperatures than at lower temperatures and the negative impacts of drier climate conditions are greater under pessimistic assumptions than they are under optimistic assumptions. These results are driven by model assumptions about the relationship between agricultural output and different levels of precipitation; they do not consider regional or seasonal variability nor do they account for possible changes in the incidence of extreme events such as drought and flooding. To date, variations in precipitation have not been routinely incorporated in assessments of the agricultural impacts of climate change; nevertheless, they are potentially quite important and could significantly affect actual benefits or damages associated with climate change in this sector of the economy. Therefore, in future assessments, more attention should be paid to the specific effects of precipitation under different climate scenarios.

5) Changes in human mortality and morbidity are small but important determinants of the modeled impacts of climate change for the U.S. economy as a

whole. An increase in climate-induced mortality or illness reduces the population of workers and consumers available to participate in the market economy, in turn leading to a loss of real GDP. In this analysis, mortality and morbidity effects alone account for 13 to 16 percent of the aggregate predicted effect of climate change on the economic welfare of U.S. households. Failure to include such effects therefore understates the potential market impacts of climate change as well as the likely benefits of climate-mitigating policies. Furthermore, the economic consequences of the mortality and morbidity effects arising from a given change in temperature are at the low end of mortality valuations found in the reported literature. Hence, the contribution of health effects to the aggregate market impacts of climate change could be even higher than these results suggest.

Taken together, these findings have important implications for current policy debates and for ongoing efforts to further refine our understanding of the likely impacts of global climate change. From a policy standpoint their primary relevance lies in the extent to which they support (or diminish) the case for intervention to avoid or mitigate the impacts being evaluated. Within the scope of this analysis, perhaps the most important point is the fact that most, if not all, potentially positive impacts of climate change under optimistic assumptions are likely to be transient and unsustainable over the long run in the face of steadily rising temperatures. If, on the other hand, pessimistic assumptions prove to be more correct, the economic impacts of climate change are not only immediately negative, but worsen steadily over time. Thus, the potential for temporary economic benefits must be balanced against the potential for immediate and lasting economic damages. A second important point is that the modeling results reveal asymmetries in the magnitude of potential benefits versus potential damages. Specifically, the economic losses estimated under pessimistic assumptions are generally larger than the transient benefits gained under optimistic assumptions in all but the low climate change scenarios. Moreover, the asymmetry becomes more pronounced with rising temperatures as certain types of costs—such as those associated with extreme weather events—increasingly offset possible benefits to other sectors of the economy.

The second study focuses on cost effective mitigation of climate change. Most discussions of the climate change issue have focused almost entirely on the human contribution to increasing atmospheric concentrations of carbon dioxide (CO_2) and on strategies to limit its emissions from fossil fuel use. Among the various long-lived greenhouse gases (GHGs) emitted by human activities, CO_2 is so far the largest contributor to climate change, and, if anything, its relative role is expected to increase in the future. An emphasis on CO_2 is therefore justified, but this has had the unintended consequence of directing attention away from the other GHGs, where some of the most cost-effective abatement options exist. The non-CO_2 GHGs emitted directly by human activities include methane (CH_4) and nitrous oxide (N_2O), and a group of industrial gases including perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), and sulfur hexafluoride (SF_6). When taken together with the already banned chlorofluorocarbons (CFCs), their climate significance over the past century is roughly equivalent to that of CO_2. Hence, to effectively limit climate change, and to do so in a cost-effective manner, thus requires that climate policies deal with CO_2 and non-CO_2 gases alike.

Designing a cost-effective approach for control of these multiple substances requires some way of accounting for the independent effects of each on climate. The current method for doing so is a set of indices or weights known as global warming potentials (GWPs). These have been developed for the main GHGs, but not for SO_2 and other local and regional air pollutants. By design, the GWP for CO_2 is 1.0 and the values for other GHGs are expressed in relation to it. These indices attempt to capture the main differences among the gases in terms of their instantaneous ability to trap heat and their varying lifetimes in the atmosphere. By this measure, for example, methane is ton for ton more than 20 times as potent as CO_2, while N_2O is about 300 times as potent, and the industrial gases are thousands of times as potent when taking into account the atmospheric effects of these gases over the next 100 years.

The relative value of controlling non-CO_2 gases, as expressed by these GWPs, is one key reason that inclusion of the non-CO_2 gases in policies to address climate change can be so effective in lowering implementation costs, particularly in the early years. Given the high carbon-equivalent values of the non-CO_2 gases, even a small carbon-equivalent price on these gases would create a huge incentive to reduce emissions. Another reason is that, historically, economic instruments (i.e., prices, taxes, and fees) have not been used to discourage or reduce emissions of non-CO_2 gases, whereas price signals via energy costs exist to curb CO_2 emissions from fossil fuels.

If, for example, the total GHG emissions reduction required to meet a target were on the order of 10 or 15 percent, as would be the case if total GHG emissions in the United States were held at year 2000 levels through 2010, nearly all of the cost-effective reductions would come from the non-CO_2 greenhouse gases. Compared to a particular reduction achieved by CO_2 cuts alone, inclusion of the non- CO_2 abatement options available could reduce the carbon-equivalent price of such a policy by two-thirds. This large contribution of the non-CO_2 gases, and their potential effect on lowering the cost of a climate policy, is particularly surprising because it is disproportionate to their roughly 20 percent contribution to total U.S. GHG emissions. In developing countries like India and Brazil, non-CO_2 gases currently account for well over one-half of GHG emissions. Any cost-effective effort to engage developing countries in climate mitigation will, therefore, need to give even greater attention to the non-CO_2 gases.

Of course, these gases are only part of an effective response to the climate threat. Even if they were largely controlled, we would still be left with substantial CO_2 emissions from energy use and land-use change. Over the longer term, and as larger cuts in GHGs are required, the control of CO_2 will increase in its importance as an essential component of climate policy.

The quantitative importance of the other non-CO_2 greenhouse gases has now been relatively well-established. One of the major remaining concerns in including them in a control regime is whether their emissions can be measured and monitored accurately so that, whatever set of policies are in place, compliance can be assured. In fact, the ability to monitor and measure has less to do with the type of greenhouse gas than with the nature of its source. It is far easier to measure and monitor emissions from large point sources, such as electric power plants, than from widely dispersed non-point sources, such as automobile and truck tailpipes or farmers' fields. Methane released from large landfills can be easily measured, and is in the United States. But, it is impractical to directly measure the methane emitted from each head of livestock, or the N_2O from every farmer's field. The difficulty of monitoring and measuring emissions implies that a different regulatory approach may be desirable for different sources, at least initially.

Scientists have long recognized the various roles of non-CO_2 greenhouse gases and other substances that contribute to climate change. It is only in the past few years, however, that the various pieces of this complex puzzle have been fit together to provide a more complete picture of just how critical the control of these gases can be in a cost-effective strategy to slow climate change. Control of non-CO_2 greenhouse gases is a critical component of a cost-effective climate policy, and particularly in the near term these reductions can complement early efforts to control carbon dioxide.